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COMPARISON OF TUNING METHODS FOR TEMPERATURE CONTROL OF A CHEMICAL REACTOR

Jacob Martin, Jr., A. B. Corripio and C. L. Smith
Department of Chemical Engineering
Louisiana State University
Baton Rouge, Louisiana 70803

ABSTRACT

This paper presents the results of applying various controller tuning methods to the feedback temperature control of a simulated chemical reactor. Specifically the minimum error-integral correlations presented by Lopez and by Rovira are compared with the Ziegler-Nichols method and the loop-compensation method previously presented by these authors. Based on speed of response and control stability the best all-around techniques are shown to be Rovira's set-point tuning and the loop-compensation method. The closed-loop responses of the reactor temperature to changes in set-point and load are presented.

INTRODUCTION

The modern control engineer finds that his task of designing feedback control systems involves the specification of the variables to be measured, the streams to be manipulated, the sensors and transmitters to do the measuring, the control valve, complete with actuator and positioner if so required, and the feedback controller. A key step in the complete operation is the tuning of the controller parameters to the dynamic characteristics of the process. The success or failure of the design process may depend on it.

The process control literature of the last four decades contains a number of tuning methods and correlation formulas for feedback controllers. Of these, we have chosen to consider in this paper the minimum error integral correlations of Rovira [1] for set-point inputs and of Lopez [2] for disturbance inputs, the pioneer method of Ziegler and Nichols [3] and the loop-compensation method proposed by Martin et al [4]. These methods are chosen because they are intended to apply in general to the most common processes. Other methods have been presented in the literature that apply to more specific processes such as the control of pH, centrifugal compressors, liquid level, etc. The methods studied here would in no way compete with the more specific methods and correlations for these process loops.

TEMPERATURE CONTROL OF A CHEMICAL REACTOR

In order to study the performance of the controller to a more realistic plant than a first or second-order differential equation, the temperature control of a continuous stirred tank chemical reactor was chosen. The reactor, which is sketched in Figure 1, was simulated on an analog computer with enough detail as to include its most important nonlinear dynamic characteristics. A detailed description of the mathematical model has been given in a previous publication [5].

The temperature in the reactor is controlled at the desired set-point by manipulation of the rate of cooling water to the jacket. Step changes in temperature set-point and load are applied to observe the response of the controller tuned by the methods under consideration. The load input is the rate of reactant feed.

The nonlinear behavior of the loop is illustrated in Figure 2 by a steady-state plot of temperature - the control variable - versus cooling water rate - the manipulated variable. The slope of this line is proportional to the process gain and is shown to increase as the cooling water rate decreases.

MODELS FOR CONTROLLER TUNING

All of the tuning methods considered here make use of correlations which are based on the parameters of either a first-order lag plus dead-time (transportation lag or time delay) or a second-order lag plus dead-time. These parameters are most commonly obtained from a process reaction curve of the process. Such a curve is the open-loop response of the controlled variable to a step-change in manipulated variable. For the reactor, a first-order plus dead-time model was obtained by a method proposed by Miller [6] and the parameters obtained are as follows:

$$\tau \frac{dT}{dt} + T(t) = KW_c(t-t_o) \qquad (1)$$

K = -0.0333 °F/(lbs/min)
τ = 13.95 min
t_o = 2.5 min

The parameters of the second-order lag plus dead-time were determined by Sten's method [7], and are as follows:

$$\frac{d^2T}{dt^2} + b\frac{dT}{dt} + cT(t) = cKW_c(t-t_o) \qquad (2)$$

$K = -0.0333$ °F/(lbs/min)
$b = 0.34$ min^{-1}
$c = 0.024$ min^{-2}
$t_o = 0.8$ min

These parameters correspond to an overdamped system with time constants of 10.1 and 4.1 min.

The process reaction curve was obtained by a step reduction in cooling water rate of 120 lbs/min. Although the parameters vary with the magnitude and direction of the step, we felt that it would be unrealistic in an industrial situation to perform multiple tests to obtain an average. A single process reaction curve is difficult enough to get.

TUNING METHODS

Rovira [1] and Lopez [2] based their tuning correlations on the first-order plus dead-time model of equation 1. They used parameter search techniques to determine the controller parameters that result in a minimum of the following error functions:

$$IAE = \int_0^\infty |e|dt$$

$$ITAE = \int_0^\infty |e|tdt$$

where $|e|$ is the absolute value of the error or instantaneous difference between the controlled variable and the set-point. Lopez also considered the integral of the squared error (ISE) but the resulting tuning parameters gave highly oscillatory responses.

While Lopez minimized the error integrals for step changes in disturbance - assuming the process dynamics to disturbance were identical to the dynamics to the controller output signal -, Rovira considered step changes in set-point, a more demanding case. This resulted in more conservative tuning parameters.

Although Ziegler and Nichols [3] did not base their tuning correlations on the parameters of equation 1, the graphically defined parameters from the process reaction curve can be converted to those of the first-order plus dead-time model. They obtained their correlations by empirical methods and based them on a quarter-decay ratio. Unfortunately, the quarter-decay ratio is a more oscillatory response than is usually acceptable in an industrial environment.

These authors' loop-compensation approach [4] consists of looking at the controller as a dynamic compensator for the other major component of the loop: the process. In his approach the integral time is considered a zero of the controller transfer function that is used to compensate for the longest time constant of the process or dominant pole. The derivative time is considered as a second zero that compensates for the second longest process time constant. With the two time parameters thus determined to insure fast loop response, the gain can then be adjusted to meet any specified response criteria. Gain correlations were obtained for 5% overshoot on the response to a step change in set-point.

Martin's approach requires the first-order plus dead-time model parameters to tune a proportional-integral (PI) controller, and the second-order plus dead time parameters to tune a proportional-integral-derivative controller (PID).

Tuning the Temperature Controller

Using the parameters obtained from the process reaction curve for the reactor, the PI controller parameters computed from the various correlations are shown in Table I. Note that the parameters from the Rovira correlation are essentially the same - within control parameter accuracy - as those from the loop-compensation approach for 5% overshoot, while the Lopez and Ziegler-Nichols correlations result in tighter control parameters. The equation for the PI controller is given by:

$$m = m_o + K_c\left(e + \frac{1}{T_i}\int edt\right) \qquad (3)$$

where e = (set-point) - T

The parameters for the PID controller are given in Table II. Note that the integral and derivative times for the loop-compensation method are of the order of magnitude of the process time constants. Again the Lopez and Ziegler-Nichols correlations result in higher gains and shorter integral time. The parameters of Table II are for the following PID controller equation:

$$m = m_o + K_c\left(e + \frac{1}{T_i}\int edt + T_d\frac{de}{dt}\right) \qquad (4)$$

COMPARATIVE SET-POINT RESPONSES

The responses of the PI controller to a 4 °F rise in set-point are given in Figure 3. The figure illustrates the closeness of the response between the Rovira and loop-compensation techniques. Lopez' tuning is not shown because it is not intended for set-point changes. The quarter-decay Ziegler-Nichols response is obviously too oscillatory. Note that the loop-compensation response exceeds the 5% overshoot for which it was designed. This is because of the nonlinear nature of the reactor which, at this higher temperature, exhibits a higher gain than measured by the process reaction curve. The nonlinear effect is evident in Figure 4, which shows the response of the PI controller to a 4 °F drop in set-point. At the lower temperature the reactor gain is lower.

The corresponding responses of the PID controller tuned by the various correlations are shown in Figures 5 and 6 for a 4 °F rise and drop in set-

point, respectively. The Rovira IAE tuning has a faster rise-time than loop-compensation tuning. It must be kept in mind, however, that the gain of the controller can be field adjusted under the loop-compensation concept, since it is determined independently of the integral and derivative times.

RESPONSES TO LOAD INPUT

The PI controller responses to a 20% decrease in reactant feed rate are shown in Figure 7. In this case the Lopez tuning is included since it is intended for load changes. Rovira's tuning is essentially the same as loop-compensation tuning for the PI controller as mentioned earlier. Note the oscillatory behavior of the Ziegler-Nichols and Lopez responses. Again it appears that the loop-compensation gain could be adjusted upwards to speed up its response. The corresponding PID controller responses are shown in Figure 8. The Lopez and Ziegler-Nichols responses are less oscillatory in this case. Again, loop-compensation is rather conservative, and seems that it could stand a higher gain.

SUMMARY AND CONCLUSIONS

Tuning techniques based on simple models of the process have been shown to result in very satisfactory responses when applied to the temperature control of a nonlinear chemical reactor. The tuning methods of Rovira and loop-compensation produced the best responses to set-point changes in terms of stability and speed of response. In general, set-point changes are more demanding in controller performance than load changes, and are equivalent to load changes when the process dynamics to disturbance inputs are much faster than its dynamics to the manipulated variable.

Although conservative in terms of responses to load changes, the fact that the loop-compensation concept decouples the adjustment of the gain from that of the time parameters allows the operator to obtain any desired response criteria by adjustment of only one knob. This is not the case for the other methods for which all of the controller parameters are interrelated.

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NOTATION

b	Second-order model damping parameter
c	Second-order model frequency parameter
e	Controller error
IAE	Integral of the absolute value of the error
ITAE	Integral of time averaged absolute value of the error
K	Model gain
K_c	Controller gain
m	Controller output signal
m_o	Initial controller output signal
t	Time
t_o	Model dead-time
T	Temperature of the reacting fluid
T_d	Controller derivative time
T_i	Controller integral time
W	Mass rate of feed (load input)
W_c	Mass rate of cooling water (manipulated variable)
τ	Model time constant

REFERENCES

[1] Rovira, A. A., P. W. Murrill, and C. L. Smith, "Tuning Controllers for Setpoint Changes", Instruments and Control Systems, Vol. 42, No. 12, December 1969, p. 67.

[2] Lopez, A. M. et al., "Controller Tuning Relationships Based on Integral Performance Criteria", Instrumentation Technology, Vol. 14, No. 11, November 1967, p. 57.

[3] Ziegler, J. G. and N. B. Nichols, "Optimum Settings for Automatic Controllers", Trans. ASME, Vol. 64, No. 11, November 1942, p. 759.

[4] Martin, Jacob, Jr., Corripio, A. B. and Smith, C. L., "Controller Tuning from Simple Process Models", Inst. Tech., Vol. 22, No. 12, Dec. 1975, pp. 39-44.

[5] Corripio, A. B. and C. L. Smith, "Computer Simulation to Evaluate Control Strategies", Instruments and Control Systems, Vol. 44, No. 1, January, 1971, p. 87.

[6] Miller, J. A., et al., "A Comparison of Controller Tuning Techniques", Control Engineering, Vol. 14, No. 12, December 1967, p. 72.

[7] Sten, J. W., "Evaluating Second-Order Parameters", Instrumentation Technology, Vol. 17, No. 9, September 1970, pp. 39-41.

TABLE I

PI CONTROLLER TUNING PARAMETERS - BACKMIX REACTOR

Techniques	K_c (lbs/min/°F)	T_i min
Loop-Compensation (5% overshoot)	-0.584	13.95
Rovira (Set-Point) (IAE)	-0.666	14.50
Lopez (Load) (IAE)	-1.072	6.805
Ziegler-Nichols (quarter decay)	-1.003	8.32

TABLE II
PID CONTROL TUNING PARAMETERS - BACKMIX REACTOR

Techniques	K_c lbs/min/°F	T_i min.	T_d min
Loop-Compensation (5% overshoot)	-0.404	14.18	2.94
Rovira (Set-Point) (IAE)	-0.968	19.46	1.01
Lopez (Load) (IAE)	-1.398	4.383	0.952
Ziegler-Nichols (quarter-decay)	-1.116	5.00	1.25

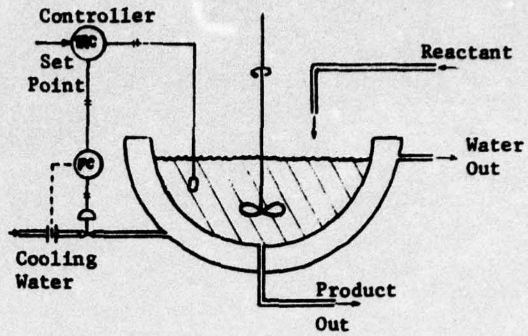

Figure 1. Reactor temperature control scheme

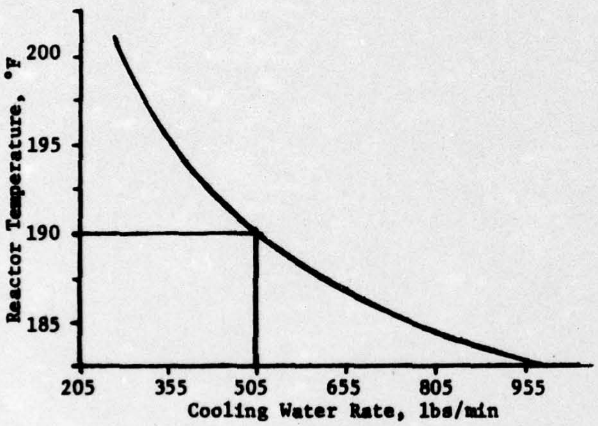

Figure 2. Reactor temperature versus cooling water rate at steady-state

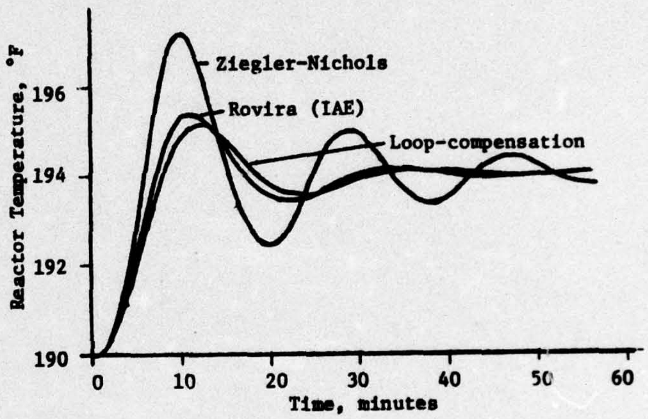

Figure 3. Closed-loop response of PI controller for a 4°F rise in set-point

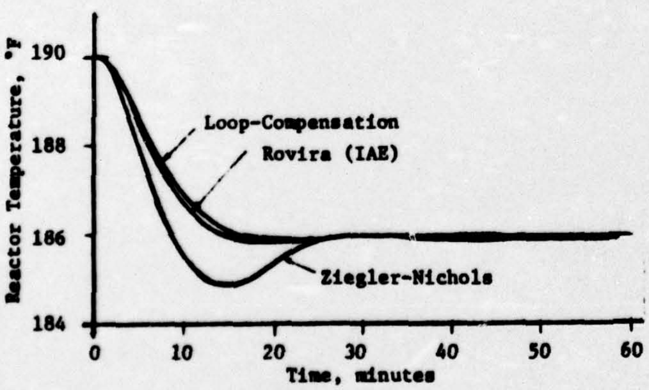

Figure 4. Closed-loop response of PI controller for a 4°F drop in set-point

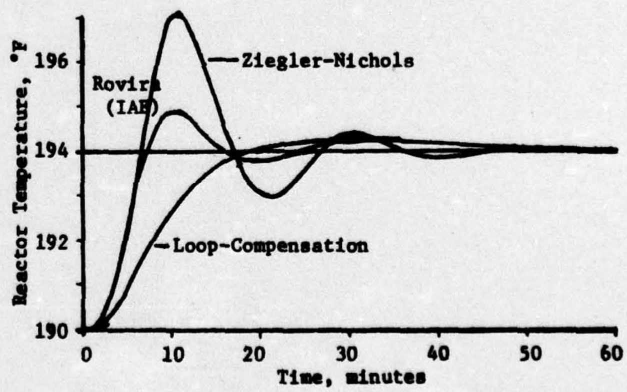

Figure 5. Closed-loop response of PID controller for a 4°F rise in set-point

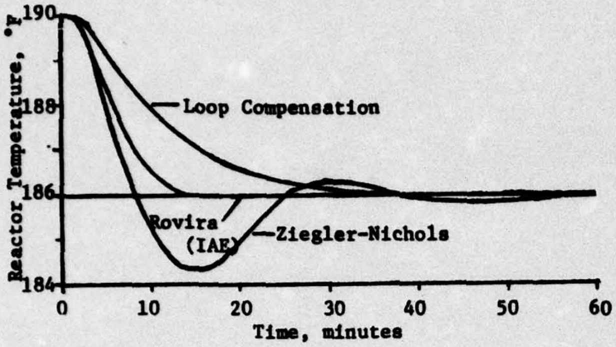

Figure 6. Closed-loop response of PID controller for a 4°F drop in set-point

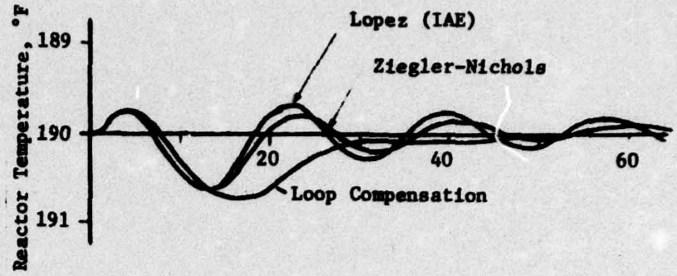

Figure 7. Closed-loop response of PI controller for a 20% decrease in reactant feed rate

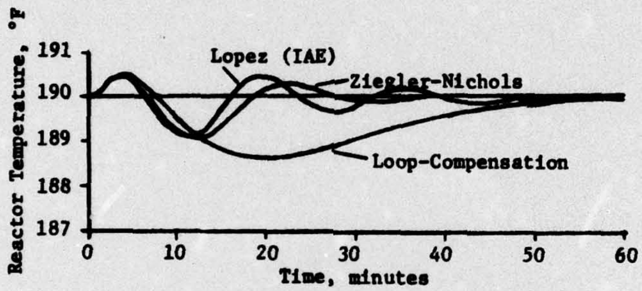

Figure 8. Closed-loop response of PID controller for a 20% decrease in reactant feed rate

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